

1 PROCESS FOR THE PRODUCTION OF PHYSICALLY FOAMED
2 INJECTION MOLDED ARTICLES

3
4 BACKGROUND

5 Technical Field

6 The present disclosure relates to a process for the production of physically
7 foamed injection molded articles and, in particular, to a process for the production of
8 physically foamed injection molded articles with an internal foam structure and a
9 compact closed-pore external skin of the same material as the base body.

10
11 Related Art

12 The production of foamed plastics, for example, is achieved with the aid of so-
13 called propellants, which expand a plastic, generally thermally softened plastic mass
14 in the desired manner. In this case, the propellants are either generated in situ via
15 chemical reaction of the components (chemical propellants), or compressed fluids, e.g.
16 N₂, CO₂, are added under pressure to the starting material, in which case a foaming
17 process of the plastic mass caused by the propellant is initiated upon the subsequent
18 drop in pressure of the component mixture to normal pressure.

19 However, chemical propellants have a series of disadvantages. For instance,
20 for use in foam injection molding higher temperatures than are actually necessary for
21 softening starting materials may have to be selected in order to reach the ignition point
22 of the propellants, since the temperature at which the reaction of the components
23 generating propellant starts is generally very high. Because of the high temperatures
24 a higher expenditure of energy is necessary during melting of the raw materials. In
25 addition, the cycle or cooling times are increased and a higher cooling power of the
26 cooling plants is necessary. In some circumstances, damage to the raw materials may
27 also occur as a result of the comparatively high temperatures.

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1 Chemical propellants which have not been converted can locate on the surface
2 of the articles obtained and cause yellowing of the articles. Allergic skin reactions
3 may also result upon contact with these articles.

4 Foam articles which have been obtained by means of chemical propellants are
5 not recyclable, or if so only conditionally, since there is the risk that non-ignited
6 propellants can lead to uncontrolled reactions during reuse.

7 Therefore, physical propellants are preferably used to foam plastics. Physical
8 propellants allow optimum adaptation of the melting temperature to the respectively
9 selected raw material, as a result of which the energy expenditure is reduced, optimum
10 cycle and cooling times are made possible and, in addition, there is no risk that the
11 raw materials could be detrimentally affected as a result of temperatures which are too
12 high. Moreover, inexpensive gases such as CO₂, for example, can be used as physical
13 propellants.

14 Physical propellants do not remain in the finished foam articles, but diffuse out
15 within a comparatively short time. Therefore, these articles are fully recyclable, since
16 there is no need to fear that propellant residues could lead to uncontrolled reactions.

17 Various processes are known for the production of articles from foamed plastic
18 with a compact closed external skin and a cellular core cohering with the external skin
19 or edge zone, also referred to as integral foam or structural foam.

20 For example, in the reaction injection molding process (RIM), two reactive
21 components are mixed together which harden and foam in the cavity of a mold under
22 reaction. Because of the quicker cooling at the wall of the mold, the reaction mass
23 solidifies more quickly there than in the interior of the mold and, as a result, the
24 foaming process ceases earlier there than in the mold interior, and a compact sealed
25 external layer is formed.

26 As determined by the process, the reactive component mixture must be
27 comparatively liquid in order to guarantee complete filling of the mold before the
28 reaction starts. However, this leads to irregularities on the surface of the formed

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1 article as a result of spray over and skin formation, which necessitates expensive
2 finishing for high-grade articles, for which a perfect surface is required.

3 Moreover, for the RIM process the mold must be treated with a separating
4 agent prior to injection, which on the one hand requires more expenditure in
5 processing and can additionally lead to residues on the finished article which must be
6 removed. The relatively long cycle times are also disadvantageous.

7 Because foaming in the RIM process is generally conducted chemically, the
8 articles to be obtained are only conditionally recyclable.

9 Integral foams made of polyurethane to be used as working material primarily
10 in the automobile industry, e.g. for steering wheel casings or gearshift knobs etc., are
11 preferably produced using the RIM process. However, for this field of application the
12 articles must not only have as perfect a surface as possible, but also have pleasant skin
13 feel (tactility).

14 It has been shown that articles of polyurethane integral foam have only a
15 conditionally acceptable tactility.

16 It is also known to produce integral foams from thermoplastic urethane or
17 thermoplastic elastomer by means of conventional injection molding processes. Both
18 chemical and physical propellants can be used in this case. Contrary to the RIM
19 process, which requires special plants, already existing injection molding plants
20 without expensive refitting can be used for this.

21 The necessary finishing of the articles obtained is only slight.

22 DE 196 46 665 A1 describes a process for metering physical propellants,
23 wherein a propellant is added at high pressure to the softened plastic material
24 transported in the consumer, e.g. an extruder or an RIM machine, and the amount of
25 propellant is regulated with a pressure control valve, which keeps the pressure
26 difference constant via a rigid throttle means by regulating the pressure difference in
27 dependence on the flow of propellant. The extrusion processes described here are
28 continuous processes in which the propellant is permanently added.

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1 A process for the production of multilayered articles with a foamed core and
2 a non-expanded thermoplastic external skin is known from DE 1 778 457, wherein a
3 first propellant-free melt and a second melt containing propellant as well as possibly
4 a third propellant-free melt are firstly prepared and injected one after the other into an
5 appropriate mold, in which case the mold must be maintained at a temperature equal
6 to or higher than the activation temperature of the propellant.

7 Where physical propellants are used, it is suggested that either the selected
8 temperature of the melt upon leaving the nozzle is so high that, when a mold with
9 constant internal volume is used, the gas formation, and thus the expansion, still
10 occurs below the pressure exerted on the substance in the mold, and when a mold with
11 extendable interior is used, the gas formation, and thus the expansion, occurs by
12 relieving the pressure exerted on the mold interior to expand the mold. There is no
13 mention of the propellant being added directly to the melt flow which flows into the
14 mold, nor of the quantity of propellant apportioned to the melt flow being regulated
15 via the pressure.

16 An improved process of the aforementioned type is specified in DE 1 948 454,
17 wherein the propellant is injected into the melt flow shortly before entry into the mold
18 and the injection period is continued until the mixture quantity required to form the
19 core has been inserted into the mold. Solvents with a boiling point preferably between
20 20 and 150°C are specified as propellants, which are to prevent premature expansion
21 under a corresponding pressure. There is likewise no mention here of a pressure
22 regulation of the added quantity of propellant to the melt.

23 A process for the production of injection molded articles with foamed core is
24 described in U.S. Patent No. 4,548,776, according to which gaseous or gas-generated
25 chemical propellant is already added to the melt in the extruder, is thoroughly mixed
26 with this and the already foamed melt is then injected into the mold.

27 In this case, the addition of propellant occurs via a porous insert at the
28 injection point, a supply valve being provided in the feed pipe. This supply valve can

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1 be connected to an automatic control device, via which the pressure of the propellant
2 to be fed is adjusted.

3 The object of the present disclosure is to provide a process for the production
4 of physically foamed injection molded articles, with which injection molded articles
5 with an integral structure, excellent surface characteristics, and excellent tactility, can
6 be obtained in a simple manner using conventional injection molding plants, thus
7 rendering expensive finishing unnecessary.

8 9 SUMMARY

10 The articles produced according to the disclosure are suitable in particular for
11 fields of application which set high quality requirements for surface structure and for
12 which a pleasant sensory feel is of advantage on skin contact. The automobile
13 industry is given as an example, for which handles, knobs such as gearshift knobs,
14 steering wheel casings etc. of the foamed plastics obtained according to the disclosure
15 can be used. However, the process according to the disclosure is in no way restricted
16 to the production of articles for the automobile industry, but is quite generally suitable
17 for the production of any desired foamed injection molded articles.

18 For example, mass-produced articles such as closing means for bottle-like
19 containers, e.g. stoppers or corks, may also be advantageously obtained according to
20 this process. Further examples are balls, spheres, fenders, floats, etc.

21 A further field of use is the production of supporting parts, for example, for
22 the aviation or automobile industry, in particular for parts where strength is relevant.

23 This object is achieved according to the disclosure by a process for the
24 production of physically foamed injection molded articles, wherein firstly in a first
25 stage a propellant-free first melt portion is fed into a cavity (initial filling), in a second
26 stage a physical propellant is added at elevated pressure to the following melt portion
27 (propellant injection phase), wherein metering of the physical propellant occurs at
28 least in a pressure regulated manner, wherein the pressure which is exerted on the
29 propellant during the propellant injection phase is greater than the pressure which is

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1 exerted on the propellant in the phases between or before or after metered addition,
2 and the expansion of the propellant occurs in the cavity, and possibly in a third stage
3 a propellant-free further melt portion is charged into the cavity.

4 This process also permits the formation of physically foamed injection molded
5 articles, the foamed core of which is completely or partially enclosed by a compact
6 closed external skin, which has been produced without the addition of propellants, the
7 core and the external skin being made of the same material.

8 The present disclosure additionally relates to a device for the metered addition
9 of propellants under elevated pressure to an expandable melt.

10 This device can also be advantageously used for the metered addition of
11 compressible propellants.

12 The propellant-free melt portion firstly fed into the cavity in the first stage
13 forms a compact closed external skin without pores in the finished foamed injection
14 molded articles.

15 Any desired fluid which expands upon corresponding pressure relief and
16 foams the melt material in a suitable manner can be used as propellant. Hence,
17 compressible fluids such as gases in liquid or supercritical phase, for example, may
18 be used.

19 The use of carbon dioxide is recommended because of its ready availability.

20 A further preferred propellant is water.

21 The starting material for the melt is not subject to any special restrictions. Any
22 desired thermoplastic melt material which is suitable for injection molding and can
23 be foamed may be used.

24 Examples are thermoplastic materials, but also further thermoplastic melts,
25 such as metallic or ceramic melts, for example. Examples of metallic materials
26 include aluminum, magnesium, zinc, tin or even precious metals.

27 The process according to the disclosure leads to weight reduction and strength
28 increase in comparison to the corresponding compact articles.

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"Pressure regulated" in the sense of the disclosure means that in the course of the process the pressure exerted on the propellant is varied for metered addition of the propellant. In this case the pressure exerted on the propellant during the propellant injection phase is greater than the pressure exerted on the propellant in the phases between or before or after metered addition. This means in the case of critical or compressible propellants, for example, that the pressure exerted in the intermediate cycle times is lower than the holding pressure of a pressure relief valve or overflow valve.

Therefore, according to the disclosure, the required proportion of propellant is added to a melt to be foamed at a defined time over a defined period of time under a defined pressure.

The magnitude of the pressure exerted on the propellant during the metered addition is determined in particular in dependence on the required quantity of propellant, the type of article to be produced as well as the selected process parameters.

The present disclosure is explained in more detail below with reference to the figures on the basis of a preferred embodiment by the example of the addition of a compressible fluid. It goes without saying that the following explanation may also be applied in principle to non-compressible fluids such as water, for example.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects and advantages of the embodiments described herein will become apparent with reference to the following detailed description when taken in conjunction with the accompanying drawings in which:

FIGS. 1A-1D show the individual stages of the process according to the disclosure for the production of physically foamed injection molded articles;

FIG. 2 schematically shows a device for executing the process according to the disclosure;

FIG. 3 is a graph showing the pressure curve during execution of the process;
and

FIG. 4 shows a variant of FIG. 1 with direct introduction of the propellant into
the cavity.

DETAILED DESCRIPTION OF THE DRAWINGS

As FIG. 1A shows, the cavity 1 of any injection molding plant is partially
initially filled in a first stage firstly with a compact propellant-free melt 6. In this
case, a feed pipe 3 for a compressed propellant is closed, for example, by a valve 4
such as a pressure relief valve 4 (overflow valve).

After the cavity 1 has been filled with a desired quantity of propellant-free
melt 6, the feed pipe 3 for the propellant is opened and the propellant is injected in
compressed, preferably liquid, state via the injection point 5. Through contact with
the hot melt, the liquid propellant turns to gas and expands under the lower pressure
in the cavity.

As a general rule the propellant is still liquid and not gaseous at the injection
point 5 itself, and therefore one cannot talk of a "gasification point" in a narrower
sense.

A mixture 7 of gaseous propellant and melt flows into the cavity 1 and causes
the cavity 1 to fill completely, in which case the propellant-free melt portion 6 which
was used for the initial filling comes to rest in the region of the cavity walls and forms
the external skin or edge zone of the injection molded article to be formed.

The cavity 1 can be ready filled as desired and required up to the maximum
filling quantity with melt mixed with propellant or, as shown in FIG. 1D, propellant-
free melt can again be fed to the cavity in a third stage. In this case a foamed article
is obtained which has a compact firm external skin right around which is formed by
propellant-free melt.

1 After foaming and hardening, the finished injection molded article, e.g. made
2 of integral foam, is removed from the cavity and the cavity is immediately available
3 again for the next charge.

4 As shown in FIG. 1D, injection molded articles, which have a cellular foamed
5 internal core and a compact firm closed external skin, are obtained with the process
6 according to the disclosure.

7 Contrary to the known foaming processes, such as those described above, in
8 which the cavity is filled completely with a melt/propellant mixture, according to the
9 disclosure an initial filling with propellant-free melt occurs firstly, as a result of which
10 the formation of a uniform closed compact external skin is effected and articles with
11 excellent surface characteristics can be obtained.

12 It is essential for execution of the process to prevent premature expansion of
13 the propellant held under pressure. This can be achieved by appropriate insulation of
14 the device and/or maintaining a suitable pressure level.

15 The metered addition of the propellant is conducted in a time- and pressure-
16 controlled manner for the process according to the disclosure. Control can be carried
17 out via a device which is also the subject of the disclosure.

18 As shown in FIG. 2, the propellant stored under pressure in a storage means
19 11, e.g. a pressure cylinder etc., is fed to a pressure control valve 10, which can be a
20 multi-way valve such as a 3/3- or 2/3-way proportional valve, and should
21 advantageously have a very quick reaction time and precise regulation.

22 During the propellant injection phase, i.e. the phase in which the propellant is
23 added to the melt, in the case of critical propellants, the compressed propellant passes
24 via a pressure relief valve 4 to the injection point 5 and there is added to the melt.

25 In this case, the dimensions of the pipes, connection pieces and also the parts
26 of the technical control system of the process are such that no premature expansion
27 in volume of the propellant under pressure is possible.

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1 In the case of a sudden increase in volume the aggregate state of the agent can
2 change, i.e. the agent changes into a gas, in which case vaporization cold is generated,
3 which would in turn block the pipes as a result of "icing."

4 An increase in temperature on the way to the injection point 5 would also lead
5 to a change in the aggregate state. For prevention, insulation of the heat-carrying
6 elements is recommended.

7 In order to prevent premature expansion, all feed pipes should be as short as
8 possible. Consequently, the pressure control valve 10 is preferably constructed to be
9 as close as possible to the injection point 5. An improvement to the control
10 characteristics of the control valve is also achieved as a result of the thus shortened
11 feed pipe to the injection point 5.

12 If critical propellants are used, a pressure relief valve or overflow valve 4 is
13 provided before the injection point 5, this valve ensuring that the pressure in the
14 device does not drop below a specific value, preferably p_{crit} at the given
15 temperature, at which the transformation of the propellant into gas would take place.
16 If, for example, carbon dioxide is used as propellant, a pressure of at least 60 bar
17 should be maintained at room temperature in order to keep the carbon dioxide in the
18 device upstream in liquid state.

19 The pressure relief valve 4 ensures that the propellant remains in compressed
20 state even during outage times of the machine, e.g. in the intermediate cycle times
21 before and after or between the propellant injection phases. A full release of pressure
22 only occurs when the machine or control system is switched off. Several pressure
23 relief valves with "falling" pressure values may also be provided so that a pressure
24 gradient is formed in front of the injection point 5 in the feed pipe section between the
25 pressure control valve 10 and the pressure relief valve 4.

26 The graph in FIG. 3 schematically shows the pressure curve for executing the
27 process according to the disclosure using the example of compressible propellants.

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1 Outside of the propellant injection phase, as in the intermediate cycle times,
2 it is sufficient to keep the device at a selected pressure, at which the propellant
3 respectively used remains in compressed, preferably liquid, state (section 20).

4 During the propellant injection phase (section 22), an elevated pressure is
5 introduced in the feed pipes through the pressure control valve 10 so that the opening
6 pressure (holding pressure) of the relief valve 4 is exceeded and the feed pipe section
7 3 up to the injection point 5 is quickly filled with liquid medium.

8 In this case, the pressure increase is proportional to the desired quantity of
9 propellant to be fed to the melt. After time "t" expires, as soon as the desired quantity
10 of propellant has been added to the melt, the pressure is reduced again to the starting
11 pressure (section 24).

12 In FIG. 3, sections 21 and 23 show the pressure build up or reduction phase.

13 The injection point 5 is preferably configured as a throttle means, e.g. as a
14 defined gap in an injector, a sintered metal injector, or a needle valve. According to
15 the disclosure, a controlled closure mechanism is located at the injection point. The
16 quick pressure increase and the resistance through the injector prevent the propellant
17 from transforming into gas, while the agent flows on from the pressure control valve
18 10.

19 The above measures ensure that the transformation of the agent into gas only
20 occurs upon exit from the injector and when in contact with the hot melt, and that the
21 inflowing melt is foamed.

22 The controlled closure mechanism can be omitted if a pressure relief valve is
23 provided.

24 After the propellant injection phase has ended, i.e. after the desired quantity
25 of propellant has been added to the melt, the pressure in the feed pipe to the injection
26 point 5 is reduced so that no propellant can flow on. However, in the pipe up to the
27 pressure relief valve 4 the starting pressure remains in order to keep the agent in
28 compressed or liquid state for the next cycle. A virtually pressure-free and thus

gaseous state prevails only in the short feed pipe section from the pressure relief valve 4 to the injection point 5 until the next cycle.

It goes without saying that this part of the plant may also be kept under pressure if required by the provision of a suitable closure mechanism which opens again at the beginning of the propellant injection phase as a result of the increasing pressure level.

The pressure control via the pressure control valve can occur automatically by providing pressure measurement points 12, 13, for example, in front of and behind the pressure control valve.

If carbon dioxide is used as propellant, for example, the plant is preferably held at an operating pressure of at least 60 bar at room temperature, so that the CO₂ also remains in compressed state during the periods between the propellant injection phases. At the beginning of the propellant injection phase, a desired working pressure of about 200 bar, for example, is built up (section 21) in order to assure an adequate flow of propellant to the melt. After the propellant injection phase 22 has ended, the pressure is reduced again to the desired operating pressure.

The injection point 5 is preferably located in the feeder pipe 3 close to the spray point "x." According to a further embodiment, as is shown in FIG. 4, the propellant can be added directly to the melt in the cavity. In this case, the injection point 5 is located directly at the cavity.

In addition, the build up of a counterpressure can be provided in the cavity 1, such as is also used in conventional injection molding processes in the so-called gas counterpressure process.

Very short cycle times can be obtained with the process according to the disclosure. Hence, the process according to the disclosure is also very well suited to the production of mass-produced articles. The short cycle times are supported by the vaporization cold resulting upon the transformation of the propellant into gas, and this causes a reduction in the cooling time, and thus also the cycle time.

1 Should there still be propellant residues present in the pore structure in the
2 core of the article after demolding, these slowly diffuse out of the article without
3 detriment to its usability or recyclability.

4 Excellent dimensional stability of the article is achieved as a result of its
5 closed firm external skin. In addition, foamed injection molded articles which have
6 a homogeneous uniform external skin and excellent tactility can be obtained with the
7 process according to the disclosure.

8 The foamed injection molded articles obtained have an excellent surface
9 quality and do not require any further finishing. It is also of advantage that the cavity
10 does not need to be treated with a separating agent.

11 The process according to the disclosure for the pressure-controlled metered
12 addition of physical propellants to an expandable melt can be conducted
13 advantageously with a device comprising a storage means 11, in which the propellant
14 is stored under pressure, a pressure control valve 10 for regulating the propellant
15 pressure and an injection point 5, which is preferably configured as a throttle means,
16 at which the propellant under pressure is added to the melt, wherein the injection point
17 5 includes a controlled closure mechanism, and in the case of critical propellants at
18 least one pressure relief valve 4 is provided which is positioned downstream of the
19 pressure control valve 10.

20 Although the above-described process and the device for the pressure-
21 controlled metered addition of propellants under high pressure can be advantageously
22 used for the production of physically foamed injection molded articles, they are, of
23 course, also suitable for other processes in which propellants are added under high
24 pressure to melts to be expanded.

25 What is claimed is:

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